Navigation in a library using smartphones

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***Abstract*—In these times, when everyone wants to do as much work as possible in the least amount of time, it is important to make the workflow as efficient as possible. Spending an unnecessary amount of time looking for things is therefore contra productive. Using the library HafenCity University Hamburg (HCU) as an example, this paper shows how the time required to find a book can be reduced by introducing an indoor navigation system for that purpose.**
Acceleration sensors are used to realize a step counter. In combination with gyroscope data a dead reckoning can be carried out. The height information is derived of barometric measurements. For additional support, routing graphs are used to constrain the walking direction. With this setup and the additional topological we achieve deviations between last estimated to wanted position less than two meters.

***Index Terms*—indoor navigation, indoor localization, dead reckoning, routing, topological support**

I. INTRODUCTION

There are many technologies to track people in indoor environments. Infrastructure-based technologies, such as fingerprinting with WLAN APs or Bluetooth beacons, but also those that do not require additional external hardware, such as inertial measurement technology.
Infrastructure-based technologies have the disadvantage that, on the one hand, costs are incurred for hardware and and on the other hand an own development must be adapted in such a way that the normal user can handle the product untrained. The advantage here is that the achievable accuracies remain the same under optimal conditions.
The advantage of inertial measurement technology is that it can be used out-of-the-box. However, due to the quality of the sensors used and the possible low robustness of the algorithms, time-dependent errors can occur. The biggest advantage for the broad use of such a system is that there is a multi-sensor system which almost every user already knows: the smartphone.
It combines measurement technology for tracking the position as well as all other, even if possibly limited, advantages of modern computers in a portable, handy device. This feature makes it possible to realize even complex applications that combine different disciplines.
Such a complex application is also represented by the presented project. In the library of the HCU an indoor navigation system is to be made available, which is to lead the user to the desired book. This is necessary because the library's stock have been brought together from three different old stocks, thus creating an inhomogeneous signature pattern. In addition, the locations of the shelves of the books are only indicated for each floor, so that on the one hand the entire floor often has to be searched for the correct shelf and on the other hand the indication of the signature area on the shelf makes recognition even more difficult.
In the following Section II related works are shown. Afterwards in Section III the application with regard to localization is described. In Section IV first results are shown, whereupon in Section V a summary and an outlook into the following work is given.

II. RELATED WORK

There are different approaches to enable an indoor navigation system via smartphone. Without further support by other sensors dead reckoning (DR) is usually used by means of step counters from accelerations and integrated rotation rate as in [1] and [2] and partly in [3].
To minimize the inaccuracies of the sensor drift, [1] and [2] use particle filters. In [1] topological information, like the distance of a particle to a routing graph, is used to weight the particles. The particles in [2] are scattered over the whole area and disappear after passing a wall.
The accuracy of particle filters strongly depends on the number of particles used. Due to the restricted performance of smartphones, however, this is limited, so that a sufficiently accurate position estimate can no longer be achieved at runtime.
Another possibility is, as in [3], to integrate acceleration twice to distances. Here the DR by smartphone is supported by using a Smartwatch attached to the ankle of a foot. It must be taken into account that the drift caused by the sensor noise increases significantly with time advances due to integration. This is particularly the case with double integration. Here, corrections are made using zero velocity update (ZUPT) when the foot is at a standstill.
An additional support by further devices, which have to be located at other places of the body, is not reasonable, because this would have to be provided by the library and furthermore this does not allow an intuitive use of the application. Accordingly, no ZUPTs can be applied, because in the use-case the user won't hold the smartphone that still that they could be calculated, and double integration would lead to significant errors after a very short time.
The position can also be supported by external sensors. This

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happens in [2] where magnetic fields are used to further weight the particles of the filter based on the received magnetic field strength. This greatly shortens the time it takes to estimate the position.
Since no new sensors are to be installed in the library, this is out of the question.

III. System setup

For a navigation system used to find rooms, an accuracy of 5 m is sufficient. In this case, this is not accurate enough, as the individual shelves are approximately 0.5 m apart. The goal is to stand with an accuracy of less than 2 m in front of the shelf. Since the shelves themselves have printed information on the signature area, this is sufficient. Any remaining errors can be detected by the user himself. Reaching the correct side of the shelf is an extended goal. Here the user should be guided into the corridors and stand in front of the correct side of the shelf (see Fig. 1).
The inertial navigation using smartphones is realized by the inertial measuring unit (IMU) (accelerometer, gyroscope) and a barometer. As already mentioned in Section II, a DR with a step counter and integration of the rotation angle is usually realized. This is also the case in this project. The step counter is an implementation according to [1].
In order to obtain a correct trajectory, the translation must be determined. On the one hand, a fixed value could be assumed (mean step length) on the other hand a step length estimation could be performed. For this purpose the step length estimation according to [4] by Weinberg with the formula (1) can be used. K is a factor that remains constant and results in a different step length based on the variation of the accelerations in the maximum and minimum amplitude (A_{max} and A_{min}) during the step. K results from the ratio between the real distance and the estimated distance of the step length estimator.

$$l_i = K * \sqrt[4]{A_{max} - A_{min}} \tag{1}$$

A variation of this is given in [5] by Ho, Truong and Jeong, where the same formula is used, but the K factor for each step is estimated. They estimate the K factor by applying a polynomial function seen in equation (2) with the average velocity v_{step} during a step. However, they use a smoothed signal from the accelerometer so that the constant of 0.68 they found for the polynomial does not apply to unsmoothed signals.

$$K_i = 0.68 - 0.37 * v_{step} + 0.15 * v_{step}^2 \tag{2}$$

Another possibility is shown in [6] by Kim et al.. In formula (3) the absolute sum of the accelerations ΣA in respect to total samples N during a step is used instead of the minima and maxima.

$$l_i = K * \sqrt[3]{\frac{\Sigma A}{N}} \tag{3}$$

The height information for the assignment of the correct floor is obtained using the general barometric height formula (4) by [7], where $p(h)$ is the air pressure measured by the barometer, so that a 2D+1D trajectory can now be formed.

$$h_b = \frac{288.15K - 288.15K * \sqrt[5.255]{\frac{p(h)}{1013.25hPa}}}{0.0065\frac{K}{m}} \tag{4}$$

The orientation as well as the positions are supported with the help of a routing graph. The algorithm in 1 changes the current orientation of the smartphone Ψ to the orientation of the graph $\sphericalangle_P$ if the distance between the routing graph is less than 0.3 m and the absolute difference between both orientations is less than 7.5°. In addition, the position is set to the base point on the graph. Thus the user moves on the graph. If the difference between $\sphericalangle_P$ and Ψ is greater than 7.5° the graph is left.

Another topological support is done if the position of the smartphone is within a predefined polygon. This marks the area of a staircase and the step length is set to the step width of a staircase step. This way one can maintain an approximated correct position, since the step length algorithms do not calculate this correctly for stairs. If no barometer is present in a smartphone, this information can also be used to artificially change the height by one stair step height.

Algorithm 1 Snap Position to Graph

```
if overline(P(x,y), BP(x,y)) < 0.3m then
    if |Ψ − ∢graph| < 7.5° then
        Ψ ← ∢graph
        P ← BP
    end if
end if
```

IV. Experimental Results

In order to determine the achievable results of the step length estimator presented in the previous Section, a test route was carried out in the HCU building. The distance covered was about 49 m. The tests was done with six different persons, but with the same smartphone. First of all the K factor had to be determined. This was done by comparing the estimated distance of each algorithm to the ground truth. Afterwards an average value for the factor was calculated and included to the algorithms, except for the mean value (0.75 m) and the estimator of Ho, Truang and Jeong. As the formula (2) is used for smoothed accelerations, we decreased the constants iteratively to get the best for unsmoothed signals. Based on this we decided to decrease it to 0.61. After recalculating the different distances an average of the difference between ground truth and the different distances of the persons could be made. The results can be seen in TABLE I.

There is basically no big difference between the algorithm by Weinberg and the one by Kim et al. As the algorithm of Kim et al. has a greater maximum deviation, we chose the Weinberg method. The possibility to estimate the K factor with (2) seems to be to inaccurate, as its deviation to the truth is more than 20 % but as mentioned in Section III this estimator expects a filtered signal according to [5], which

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TABLE I: Results of the tests for the different step length estimator with six different Persons (P1-P6). Values are the absolute difference to the ground truth in percent

P	Weinberg [%]	Kim [%]	Ho [%]	mean [%]
P1	7.0	5.7	12.9	11.7
P2	5.8	2.7	28.0	13.1
P3	8.0	5.5	32.9	17.9
P4	5.8	8.6	15.7	0.5
P5	0.3	8.1	26.5	20.9
P6	2.7	3.5	21.1	1.5
Mean	4.9	5.7	22.8	10.9

wasn't done in this case. The method by applying a mean step length turns out to be better than that, but compared to the estimators of Weinberg and Kim et al. it performs worse than them.
Eventually the K factor (for the Weinberg method) was taken into the account for the following tests. The whole system was tested in the library of the HCU. The starting point of the test was on the ground floor of the library in front of the stairs and the destination was a shelf on the 1st floor. This route was run 13 times and the difference between target and actual position was calculated. The results are shown in Fig. 1. There the blue crosses represent the last estimated position of the tests, the red cross the end node to be reached, the red rectangle the corresponding shelf and the green line the approximate course of the different tests. In the Fig. 1 it can be seen that the results

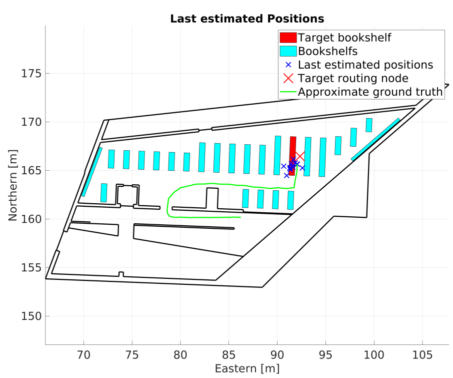

Fig. 1: Results of the position estimated in the library

are all scattered in the range of maximum 2 m around the true position and are also rather southwest. This indicates that the step counter counts too few steps. The mean deviation is 1.35 $\pm$ 0.5 m. This is a accuracy of 4 % of traveled distance.

V. Conclusion and Outlook

Since the stock of the library was merged of three different old ones, the book signatures are inhomogeneous. This and the inaccurate description of the location (only to the floor), lead to a unnecessary big time to find a book searched. Because of that this paper presents an application and the algorithms used to navigate trough the library in order to lead the way to the book looked for.
In general other works show, that results with an accuracy of 2-5 m is achievable, but in this particular case a higher accuracy was required. In order to achieve this, we added topological support by taking the routing graph into account. To overcome the problem if there is no barometer present in a smartphone, a topological support can be used to define areas where height changes are possible like on stairs. However, this hasn't been compared to the barometric height estimation, which is planned for the next investigations. Further we investigated different step estimators to improve the accuracy of the translation between two positions. In the past we used a mean step length, which worked fine, if one user would use the application, but since the application is meant to be usable to everyone this would turn out to be a big error source. Because of the results in Section IV we decided to use the the method of Weinberg, but we will do further investigate the algorithm of Ho, Truong and Jeong, because according to their work, the results should perform better.
The requirement of less than two meters is satisfied as the experimental results are within this range. Nevertheless the last estimated position don't match the requirement to stand before the correct side of the shelf. This seems to be due to to less recognized steps, so the step counters parameters have to be tweaked.
Another possibility to overcome these last deviation is to implement more sensors. For example, the camera could be used to identify the shelf in front of which the users are located, and and give feedback if the user has to go further. Also it may be worth to implement the camera as a source of position estimation doing structure from motion.

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